Quark-gluon densities in the nuclear fragmentation region in heavy ion collisions at LHC

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update of Frankfurt and Strikman: **Phys.Rev.Lett.91:022301,2003**

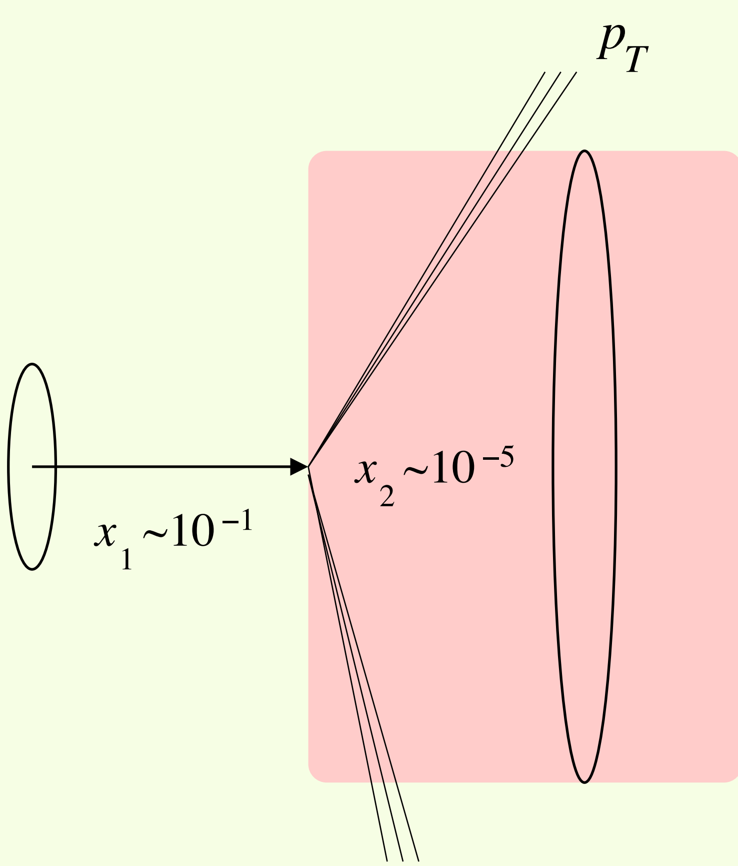
PANIC05

Aim - properties of the quark - gluon system produced in the central AA collisions in the nucleus fragmentation region

Claim - energy densities > 300 GeV/fm^3

at least as high as those expected for the central region

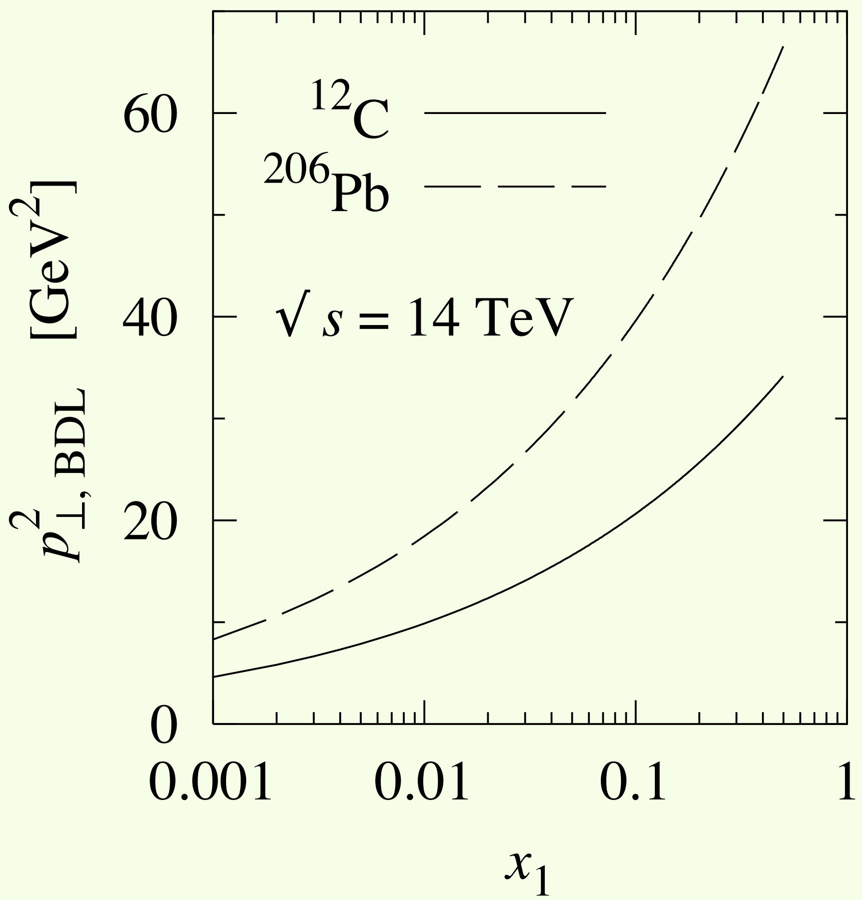
Starting point - *propagation of nucleon through strong extended gluon fields*



High x_1 parton is sensitive to the gluon fields at $x_2 = 4p_T^2/x_1 s$

The black–disk limit (BDL) in central pA collisions: Leading partons in the proton, $x_1 \sim 10^{-1}$, interact with a dense medium of small–x_2 gluons in the nucleus (shaded area), acquiring a$_2$large transverse momentum, p_T.

The average p^2_T for a parton passing through the nuclear media at small impact parameter can be estimated using unitarity considerations for the scattering of a small color dipole (Frankfurt, Weiss, MS)

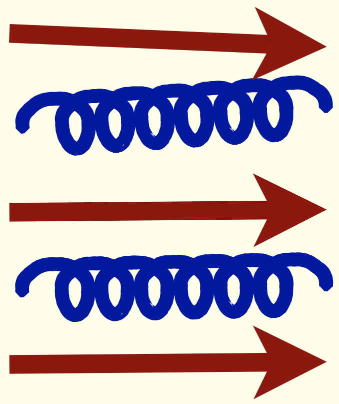


Average p^2_T (gluon) for b=0 - for quarks p^2_T is a factor of 2 smaller

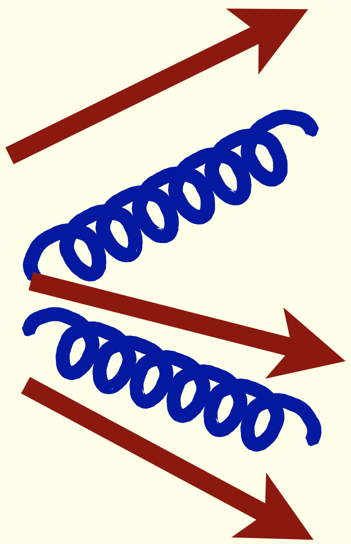
New NLO approach for getting a lower limit on p_T (Frankfurt, Vogelsang, MS) leads to

p_T (gluon) > 4 GeV/c for x > 0.1

p_T (quark) > 2.5 GeV/c for x > 0.1



Leading quarks and gluons of the nucleon **before** passing through the nucleus



Leading quarks and gluons of the nucleon **after** passing through the nucleus

Consider AA scattering in the rest frame of one of the nuclei

Let us determine the emission angle θ *of the parton belonging to the nucleus which was in rest*

Light-cone fraction is approximately conserved ➡ $(E_i - p_i^z) = x m_N,$

➡ $$p_z = (\mu^2 + p_t^2)/2xm_N - xm_N/2 \approx p_t^2/2xm_N.$$

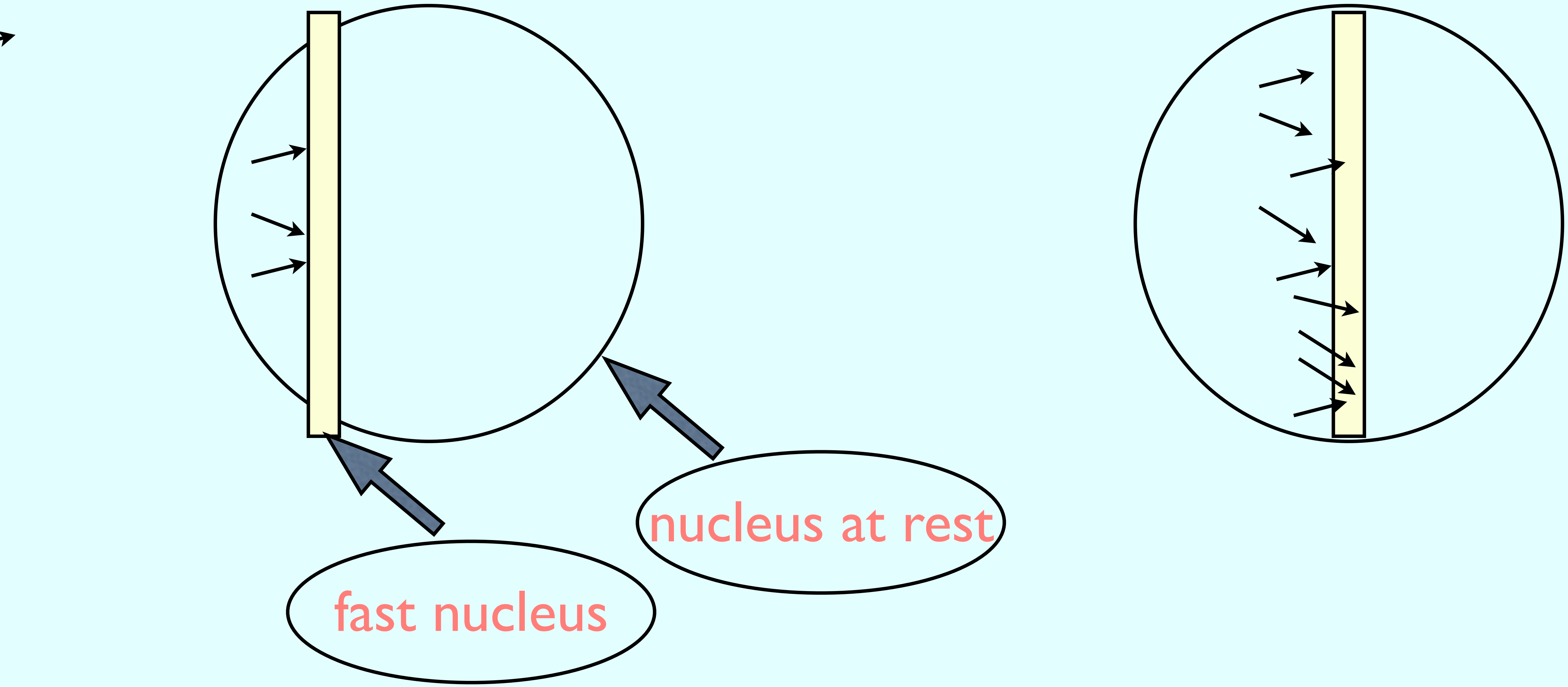
where $\mu^2 \ll p_t^2$ is the virtuality of the parton

➡ $$\theta = p_t/p_z \sim 2xm_N/p_t,$$

If p_t is large enough ($>m_N$) and x is close (smaller) than average,

the emission angle is small !!!

Knocked out parton nearly follow the fast nucleus



Resembles implosion in early designs of H-bomb

The length of the produced wave package is reduced from a naive value of $2\ R_A$ by a large factor

$$S = 1/(1-\cos\theta) \approx p_t^2/2x^2m_N^2.$$

However, we must also take into account that the products of the nucleon fragment as a whole move forward in the target rest frame. Since the knocked partons carry practically the whole light cone fraction of the nucleon, we can write for the mass^2 - M^2 and its longitudinal momentum, p_z the following relations:

$$(\sqrt{M^2+p_z^2}-p_z)/m_N = 1, \qquad M^2 = \sum_i p_{i,\ t}^2/x_i$$

$$p_z = M^2/2m_N$$

$$\gamma = E/M = \sqrt{M^2+(M^2/2m_N)^2}/M \approx M/2m_N.$$

As a result we find the total reduction in the volume:

$$\boxed{D = \frac{2m_N}{M} \frac{< \frac{p_t^2}{x^2} >}{2m_N^2}.}$$

If we make a simplifying assumption that all x_i and $p_{t\,i}$ are equal

$$D = M/m_N = Np_t/m_N.$$

Under the same assumption the energy of all partons is p_t . ➡
The ratio of the energy density of the system to that of the nuclear density, R_E

$$R_E = D \cdot Np_t/m_N = N^2 p_t^2/m_N^2$$

➡ Energy density quadratically depends on average transverse momentum of partons

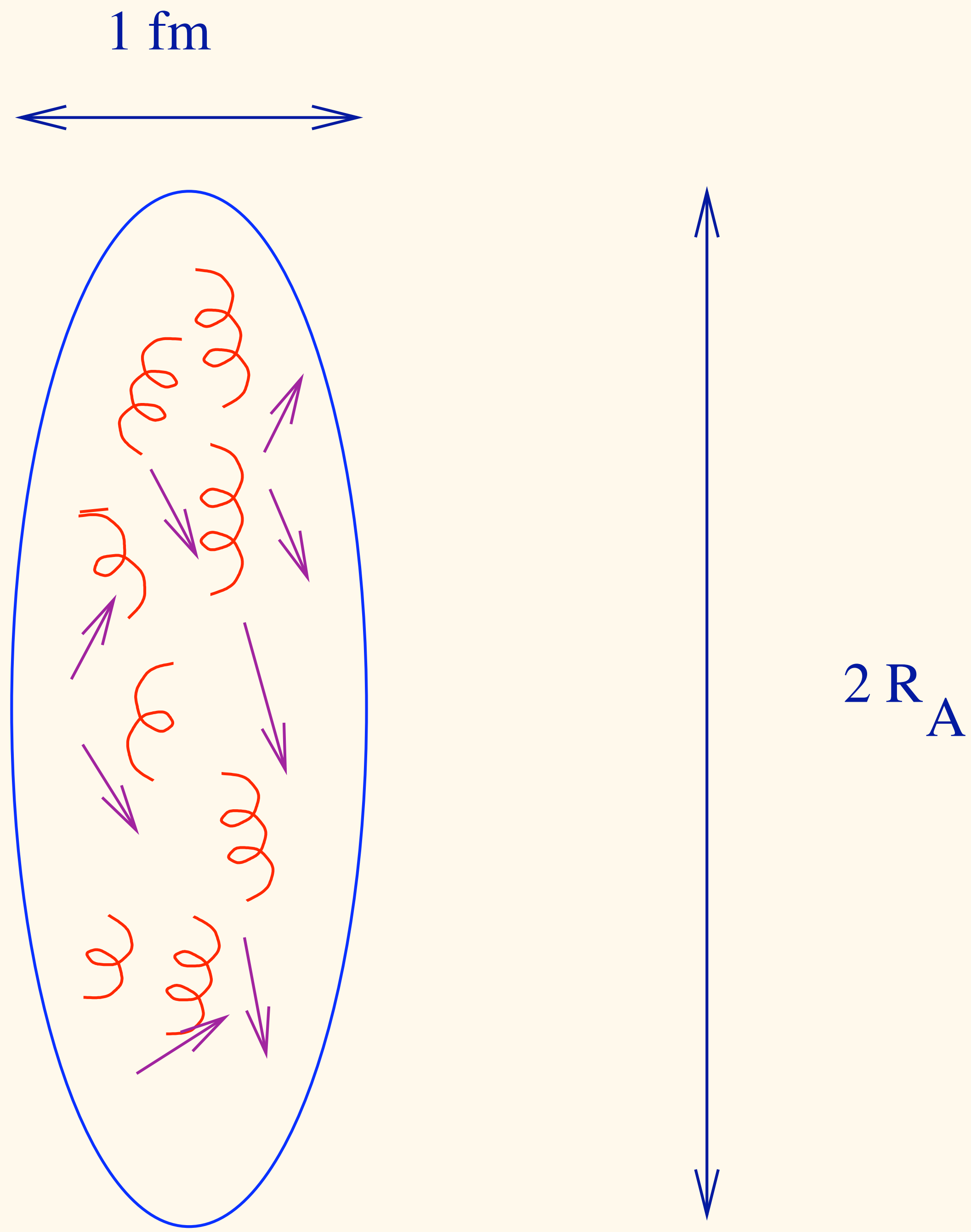
General case

$$R_E = \frac{1}{N_q + N_g} \sum_i p_i^2{}_t / m_N^2 x_i^2$$

Taking for illustration for LHC for the resolution scale 3 GeV

$$N_q = 3, x_q = 1/6, N_g = 6, x_g = 1/12$$
$$p_t^2(gluon) = 16\, GeV^2,\ p_t^2(quark) = 5\, GeV^2$$

$R_E \sim 1800$ Energy density = 300 GeV/fm^3



Quarks and gluons have predominantly transverse momenta with the third component of momentum being opposite for quarks and gluons

Sketch of imploded quark-gluon system in its rest frame

Note that most of the energy of the colliding nuclei is stored in these two (forward and backward) disks !!!

Formed state has parton density $\geq 70\, partons/fm^3$

At the higher rapidity end, "qg" ellipsoid boarders essentially parton free space; on the end close to central rapidities, it boarders a hot $q\bar{q}g$ state. We estimate that though disk is rather thin interaction cross section is large enough for partons to interact. However it is not clear whether there is enough time for thermalization.

The large angle rescatterings of partons will lead to production of partons at higher rapidities and re-population of the cool region.

Signals:

- Production of leading ($x > 0.1$) charm, beatty mesons and χ_c, χ_b mesons with rather large transverse momenta due to processes of gluon- gluon fusion in the final state: $gg \to c\bar{c}, gg \to b\bar{b}$

- Enhancement of the leading photon production via $gq \to \gamma q$.